NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2778

STRESS AND STRAIN AT ONSET OF CRAZING OF POLYMETHYL METHACRYLATE AT VARIOUS TEMPERATURES

By M. A. Sherman and B. M. Axilrod

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SUMMARY

The stress and strain at the onset of crazing of polymethyl methacrylate were determined at 23°, 50°, and 70° C. The materials tested were commercial cast polymethyl-methacrylate sheets of both general-purpose and heat-resistant grades. Most of the tests were made on samples 0.15 inch thick. Load-elongation graphs were made during the tests and the onset of crazing was observed visually and noted on the graph.

The results indicate that a "critical-strain theory" for the threshold of crazing, as has been suggested for polystyrene by Maxwell and Rahm, is not applicable to polymethyl methacrylate. The strain at the threshold of crazing tended to decrease with increase in temperature from 23° to 50° C. Between 50° and 70° C no consistent trend for the strain at crazing was detected. The stress at the threshold of crazing was about 80 to 95 percent of the tensile strength at all temperatures.

INTRODUCTION

An investigation of the rheological and crazing properties of polystyrene by Maxwell and Rahm (references 1 and 2) indicated that there is a so-called "critical elongation," 0.75 percent, for its threshold of stress crazing and that this strain is constant for temperatures below 82° C, the second-order transition point for polystyrene. In these experiments to obtain the critical elongation, the time of test was relatively short, ranging from 0.5 to 10 minutes.

Sauer, Marin, and Hsaio (reference 3) found this critical-elongation hypothesis of crazing to be inconsistent with their data on polystyrene. In some of their short-time tensile tests no crazing was evident up to failure of the specimens at an elongation of about 1.4 percent. In long-time tests of several hundred hours' duration crazing was evident at much lower strains than 0.75 percent. These authors stated that crazing is markedly dependent on the time of load application as well as on the stress or strain magnitude.

An investigation of the crazing characteristics of polymethyl methacrylate at room and elevated temperatures was undertaken to determine whether a "critical-strain theory" might be applicable for this material for short-time tests. The experiments were made on both general-purpose and heat-resistant grades of polymethyl methacrylate at 23°, 50°, and 70° C. The properties measured were tensile strength, total elongation, modulus of elasticity, and the stress and strain at the onset of crazing. These experiments were carried out as one phase of a research program to investigate factors affecting crazing of acrylic glazing. The investigation was conducted at the National Bureau of Standards under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

The helpful suggestions of Mr. W. F. Bartoe of the Rohm & Haas Co., Inc., and Mr. R. Leary of E. I. du Pont de Nemours & Co., Inc., during the course of these experiments and the courtesy of these companies in furnishing the materials for use in this investigation are gratefully acknowledged. The assistance of Mr. Victor Cohen in performing some of the experiments and Mr. John Mandel in supervising the statistical analysis is appreciated.

MATERIALS

Samples of cast polymethyl-methacrylate sheets of general-purpose grade — Lucite HC201 and Plexiglas I-A — and of heat-resistant grade — Lucite HC202 and Plexiglas II — were used. Each of the four samples consisted of three sheets of 0.15-inch nominal thickness, each from a different production run. These will be referred to as the "representative samples." These sheets, like those used to make laminated acrylic glazing, were masked on one side only with the usual adhesive-coated masking paper. Some preliminary tests were made on specimens of Lucite HC201 and HC202 of 0.125-inch nominal thickness, not masked on either side. A description of the materials appears in table I.

TEST EQUIPMENT AND PROCEDURE

Preliminary tensile tests were made in a 2400-pound-capacity Baldwin-Southwark universal hydraulic testing machine located in a controlled-atmosphere room operated at 23° C and 50-percent relative humidity. The specimens were standard tensile specimens with a 0.5-inch reduced section, Type I of Method No. 1011 of Federal Specification L-P-406a. The tests were conducted in most details according to Method No. 1011. The load-elongation graphs were produced automatically by a strain gage and the associated autographic recorder. The strain gage used was a model PS-7 Southwark-Peters plastics extensometer, a low-magnification nonaveraging type with a 2-inch gage length and a strain range of 50 percent. The magnification used was 20. The crazing was observed by viewing the specimen against a dark background with the incident light striking the specimen obliquely from behind. The light used for observing the crazing was, in general, that from a north window; on darker days, however, most of the light came from overhead fluorescent lights. The onset of crazing was noted on the load-elongation graph. The crazing observations on the specimens of samples L1bu and L2au were made by a different observer from the one who made the observations on the representative samples.

The tensile tests on the representative samples at 23°, 50°, and 70° C were made in an insulated temperature-controlled cabinet that had been used previously for determining the tensile properties of laminated plastics (reference 4). The cabinet was set up in a 60,000-pound-capacity Baldwin-Southwark universal hydraulic testing machine as shown in figure 1. This machine was located in a controlled-atmosphere room operated at 23° C and 50-percent relative humidity. Inside the cabinet (fig. 2) were the tensile grips and strain gage, the latter mechanically connected by a torque tube to the selsyn motor outside the cabinet. The motor activated the autographic recorder to produce the load-elongation graphs. On the front of the box were armholes to permit manipulation of the specimen and gage. In the rear panel of the cabinet were two openings for the circulation of air through insulated flexible tubes from the conditioning unit shown at the right in figure 1. Also inside the testing cabinet in the left rear corner was a lamp — a gooseneck desk type with hemispherical reflector — so placed as to permit observation of crazing as it developed on the specimens. The crazing was observed by looking through the right corner of the triple-paned 12- by 12-inch window on the front of the box. Black paper placed on the left and rear walls of the cabinet provided a suitable background. Because of the position of the selsyn motor which couples mechanically to the gage, the plane of the flatwise surface of the specimen was necessarily perpendicular to the window, as is shown in figure 2. Although this meant that the observer looked quite obliquely through the specimen, the crazing was not difficult to see.

The tests at 23° C were made with the cover of the box in place in order that the lighting conditions for observing the crazing would be the same as at the higher temperatures. As the light inside the box produced considerable heat it was necessary to place dry ice in the conditioning unit to run the test at 23° C. The relative humidity in the box under these conditions was found to be between 48 and 49 percent.

For the tests at 50° and 70° C each specimen was placed in the box approximately 0.5 to 1 hour before it was tested. All specimens had been conditioned at 23° C and 50-percent relative humidity for a period of at least 3 weeks before the test.

The specimens and the test procedure were as described for the preliminary tests. Up to 10-percent elongation of the specimen, the tests were run at 0.05 inch per minute. As the specimens at elevated temperature and sometimes at room temperature stretched 100 percent or more, the gage was removed at the 10-percent elongation point and the rate of head motion increased to about 0.6 inch per minute. The permanent set of the specimen within a few minutes after breaking was measured with a steel scale. This increase in speed did not affect the values for properties reported other than elongation, as the crazing occurred and the maximum strength at 0.05 inch per minute was reached at less than 10-percent elongation. The load on the specimen increased, of course, when the speed was increased to 0.6 inch per minute and, in some cases, increased to a value above the maximum for 0.05 inch per minute.

PRELIMINARY TESTS

Exploratory tensile tests were made on four specimens of Lucite HC201 and of Lucite HC202. Two of the Lucite HC202 specimens were annealed by being held between glass plates at 100° C for 1 hour and then allowed to cool slowly to room temperature. Some specimens were tested at a cross-head speed of 0.05 inch per minute and others at 0.25 inch per minute; the tests were made at 23° C and 50-percent relative humidity.

The values of the stress, expressed as percentage of maximum stress, and of the strain at the threshold of crazing for these specimens are as follows:

Material	NBS sample	Cross-head speed (in./min)	Threshold strain for stress crazing (percent)	σ_c/σ_{max} (percent) (a)
Lucite HC201	L1bu	0.25	2.9, 3.3	88, 96
Lucite HC201	L1bu	.05	2.0, 2.6	85, 94
Lucite HC202	L2au	.25	3.0, 3.2	87, 90
[b]Lucite HC202	L2au	.25	4.8, 3.5	96, 90

[a]Ratio of threshold crazing stress, σ_c, to tensile strength, σ_{max}.

[b]Annealed specimens.

The strain at crazing for the untreated specimens tested at 0.25 inch per minute was about 3 percent for both the general-purpose and the heat-resistant grades. The slightly lower value of threshold strain for the tests at 0.05 inch per minute may actually be a speed effect; however, it also may be due to a lag on the part of the observer in judging the threshold of crazing in the tests at the higher speed.

The annealed specimens show a higher threshold strain than the corresponding untreated specimens. Maxwell and Rahm (reference 2) found that heat-treated polystyrene had a threshold strain for crazing of 0.96 percent as compared with 0.75 percent for the untreated material. A greater change might be expected with the polystyrene because these specimens, which were compression-molded, would probably have greater residual stresses prior to annealing than would the cast polymethyl-methacrylate specimens.

To investigate further the effect of time on the strain at the threshold of crazing, standard tensile specimens were subjected to static loading in a long-time loading frame which is described in reference 5. Constant stresses of 4000 and 5000 psi were applied to the specimens of Lucite HC201 and HC202, respectively. The strain was observed in each case with a Tuckerman optical gage on one face of the specimen. The values obtained are as follows:

Material	NBS sample	Applied tensile stress (psi)	Threshold strain (percent)	Time to craze (hr)
Lucite HC201	L1bu	4000	[a]1.4, 1.4	3, 4
Lucite HC202	L2au	5000	1.8, 2.1	5, 5

[a]Interpolated, gage had been jarred.

Since the crazing begins at a strain of about 2.5 percent in a few minutes in the standard tensile test, it appears that the strain at the onset of crazing probably varies only slowly with time for onset times between a few minutes and a few hundred minutes.

TESTS AT VARIOUS TEMPERATURES

The results of the tensile tests on the representative samples at 23°, 50°, and 70° C are given in table II. The average values for the tensile strength, permanent set, secant modulus of elasticity, and the stress and strain at the onset of crazing are given for each of the four materials. Statistical analysis of the tensile strength and the strain at the threshold of crazing showed sheet-to-sheet variation for most of the samples. Therefore, ranges are given as a measure of the dispersion rather than a standard-deviation or standard-error value. The values of tensile strength and of stress at the onset of crazing for the four materials are shown graphically in figure 3, the modulus values in figure 4, and the values of the permanent set and the strain at the onset of crazing in figure 5.

Strength Properties

As can be seen in figure 3, the tensile strength decreases quite linearly for all materials as the temperature is increased. For the general-purpose-grade samples the strength at 50° C is about 60 percent of its value at 23° C; at 70° C it is 28 percent of the strength at 23° C. For the heat-resistant-grade samples the strength at 50° C is two-thirds that at 23° C and at 70° C it has been reduced to a little less than one-half of the value at 23° C. The values of the tensile strength at 70° C for the Plexiglas samples agree closely with those published by the Rohm & Haas Co., Inc., (reference 6). The values in the present report are 2300 and 5100 psi for the general-purpose and heat-resistant grades, respectively; the values from reference 6 are 2400 and 5000 psi for the same materials, respectively. The rate of cross-head motion for the tests described in reference 6, however, was 0.2 inch per minute compared with 0.05 inch per minute for those described here.

The secant modulus of elasticity was found in each case for a stress range of from zero to about one-half of the maximum stress, as is shown in table II. The modulus also decreases as the temperature increases, as figure 4 shows. For the two general-purpose-grade samples the modulus decreases more rapidly than for the heat-resistant grades; at 70° C it is about 40 percent of its value at 23° C. The modulus values at 70° C for Lucite HC202 and Plexiglas II are about 60 and 70 percent, respectively, of their values at 23° C.

The permanent set instead of the total elongation is given in table II as the elongation was obtained for only three of the specimens tested at elevated temperatures. Since the test was speeded up from 0.05 inch per minute to approximately 0.6 inch per minute upon removal of the gage at 10-percent elongation, the specimen broke sooner and at a smaller strain than if the test had been continued at the slower speed. However, since all specimens were tested alike, the permanent-set values give some idea of the change in elongation with temperature. As the strain at failure is a flaw-dependent property, the dispersion for total elongation and hence for the permanent set would be expected to be high.

The ranges in table II show this to be the case. It will also be noticed that the permanent set increases considerably with rise in temperature. This, of course, is expected as the material approaches its rubbery state, which begins at about 110° and 130° C for the general-purpose and heat-resistant grades, respectively. The values of permanent set for the general-purpose-grade material are higher than the corresponding heat-resistant-grade values except in one case, namely, Lucite HC202 at 23° C, which is probably not significant. The permanent-set values for the general-purpose-grade material at 70° C could not be obtained as the maximum separation of the grips in the elevated-temperature test was quite limited. The maximum grip separation corresponded to a permanent set of about 2.2 inches for the 2-inch gage length or about 110 percent.

Crazing Properties

From the graph of the values of the strain at the threshold of crazing (fig. 5), it would appear that from 23° to 50° C this value decreases for all materials and from 50° to 70° C increases for the two general-purpose-grade materials and decreases for the sample of Plexiglas II. A statistical analysis showed that not all of these apparent differences are significant. For Lucite HC201 there was no significant difference between the strain values for the three temperatures. The Plexiglas I-A and the Lucite HC202 showed a significant change only between the strains at 23° and 50° C. The Plexiglas II showed significant decreases from 23° to 50° C and from 50° to 70° C. This indicates that for all the materials except the general-purpose-grade Lucite the strain at the threshold of crazing is not constant even for temperatures considerably less than the second-order transition point. The second-order transition points are between 75° and 80° C for general-purpose grade and about 94° to 95° C for the heat-resistant polymethyl methacrylate.[1]

In figure 6 the strain at the threshold of crazing is shown on the same graph with total-elongation data at various temperatures for three samples of polymethyl methacrylate. These elongation data were obtained earlier in this laboratory on another project (unpublished report to the Office of the Quartermaster General). If it is assumed that as the temperature decreases below 23° C the strain at the threshold of crazing continues to increase or at least does not decrease, then there will be some temperature below which the specimen will break before showing any crazing. If the strain increases more or less linearly with decrease in temperature, this point would be between -20° and 10° C for the

[1]These values were obtained by Mr. V. Cohen who made volume-temperature measurements for these samples over the temperature range of 25° to 110° C; a mercury dilatometer was used.

general-purpose-grade materials and between 0° and 10° C for the heat-resistant-grade material.

It would also appear that the strain at the threshold of crazing does not continue to decrease with increase in temperature but, after a certain point of minimum strain value, the strain at crazing begins to increase with rise in temperature. Although the statistical analysis did not show a significant increase in strain from 50° to 70° C for any material and in fact showed a significant decrease for one material, Plexiglas, the above postulate is consistent with the data. As the values of the strain for the two general-purpose materials are both higher at 70° C than at 50° C, it is possible that the strain actually has a minimum value in the vicinity of 50° C, although the data obtained herein were not taken at temperatures sufficiently above this point to detect a significant increase in strain. For the heat-resistant-grade material such a minimum may be near 70° C as for Lucite HC202 the threshold strain values at 50° and 70° C are the same. The assumption of an increase in the threshold crazing strain as the material approaches the rubbery stage is plausible because in the rubbery stage the material can be stretched very large amounts without showing any crazing.

The stress at the threshold of crazing, as can be seen in figure 3, decreases with increasing temperature very nearly at the same rate as the tensile strength; that is, the ratio of the threshold crazing stress to the maximum stress, σ_c/σ_{max}, remains fairly constant for all materials. The variation in this ratio appears to correlate very closely to the variation in strain at the onset of crazing.

A rather qualitative explanation of the temperature dependence of the threshold crazing stress may be made using a concept similar to that proposed by Maxwell and Rahm (references 1 and 2). These authors suggest that a crazing crack starts at a region in which the general orientation of the polymer chains is normal to the applied tensile stress.[2] Similarly a crazing crack could start in a region in which portions of adjacent polymer chains are so oriented. Under sufficient stress the van der Waals' forces between segments of adjacent polymer molecules in this region are overcome and a separation occurs. Such a separation occurs at the surface of the material rather than in the interior probably because surface irregularities result in stress concentrations at the surface. After forming, a crazing crack spreads until a region is reached in which the polymer chain segments are oriented predominantly parallel to the stress; the crack does not grow or grows slowly unless the material is strained further. As for the effect of temperature on

[2]Hsiao and Sauer (reference 7) suggest a mechanism of crazing based on orientation of domains of molecules, which is somewhat similar to the concept of Maxwell and Rahm.

the crazing, consider again the initiation of the crack. As the temperature is raised the amplitude of thermal vibration of the chain segments is increased. Also the average distance between segments of neighboring chains is increased. Accordingly, with increasing temperature less stress is required to cause the initial separation of portions of adjacent polymer molecules. Since crazing is the beginning of failure, it may then be expected that the ratio of the threshold crazing stress to the ultimate strength should not vary much with temperature, as is found (fig. 3).

In connection with another phase of the investigation of the crazing of acrylic material (reference 8), data were obtained earlier on the stress and strain at the threshold of crazing as well as on the tensile strength and total elongation of the representative samples. The equipment described herein for the preliminary short-time tests was used. The data, which appear in table III, indicate that the strain at the threshold of crazing is approximately 2.5 percent for three of the four representative samples and about 2.0 percent for the fourth sample, Lucite HC201 (sample L1d). The average stress at the threshold of crazing for these tests was very nearly 85 percent of the maximum stress for all samples except the Plexiglas I-A (sample P1a); it was close to 90 percent for this sample.

A statistical analysis of the strain data for the threshold of crazing at 23° C from both tables II and III indicates sheet-to-sheet variability only for the two heat-resistant samples. No significant within-sheet variation was found for any of the samples. The data for the general-purpose Plexiglas were much less precise than those for the other materials.

A highly significant difference was found between the two sets of tests at 23° C done at different times. This difference is evident from the tables without an analysis. Both the stress and strain at the threshold of crazing are higher for all materials for the 23° C tests made in the high-temperature box (table II) than for those made without a box surrounding the specimens (table III); that is, the crazing was observed later in each case in the tests made in the box, even though the specimens were from the same samples and the observations were made by the same person. This shows the dependence of the observation of crazing on factors that are sometimes difficult to control. The principal difference between the two sets of tests was the lighting conditions. Another factor that might have affected the observation of the crazing is the time lapse — about 5 months — between the two sets of tests. The fact that the two sets of specimens were tested on different machines would not be expected to influence the crazing observation.

CONCLUSIONS

From an investigation of the crazing characteristics of polymethyl methacrylate at temperatures of 23°, 50°, and 70° C to determine whether a "critical-strain theory" might be applicable for this material, the following conclusions may be drawn:

1. Polymethyl methacrylate does not begin to craze at the same strain for all temperatures; in general, the strain decreases with increase in temperature. For three of the four samples tested the strain at crazing was significantly lower at 50° C, well below the second-order transition point, than at 23° C.

2. The ratio of the stress at the threshold of crazing to the maximum stress, in general, was between 80 and 95 percent for all the samples at 23°, 50°, and 70° C.

3. The observed threshold of crazing depends on the lighting conditions and also on the observer's visual acuity, so that the values of stress and strain at crazing are relative. Tests made under different lighting conditions or with different observers may not be comparable.

4. The tensile strength and secant modulus of elasticity decreases approximately linearly with increase in temperature. The strengths at 70° C of the general-purpose and heat-resistant grades of polymethyl methacrylate were reduced to about 30 and 50 percent, respectively, of the strengths at 23° C. The modulus values at 70° C were correspondingly reduced to about 40 and 70 percent of the values at 23° C.

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Washington, D. C., Aug. 4, 1951

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TABLE I

DESCRIPTION OF POLYMETHYL-METHACRYLATE SAMPLES

Material	NBS sample	Date received	Nominal thickness (in.)	Batches in samples	Sheets in sample	Sheet size (in.)	Masking paper
Lucite HC201	L1bu	4/49	0.125	1	1	36 by 38	None
Lucite HC202	L2au	3/49	.125	1	1	36 by 48	Do.
Lucite HC201	L1d	9/49	.150	3	3	[a]36 by 48	One face only
Lucite HC202	L2d	9/49	.150	3	3	[a]36 by 48	Do.
Plexiglas I-A	P1a	10/49	.150	3	3	[a]36 by 48	Do.
Plexiglas II	P2a	10/49	.150	3	3	[a]36 by 48	Do.

[a]For convenience, sheets were cut in half at factory.

TABLE II

TENSILE TESTS OF POLYMETHYL-METHACRYLATE SPECIMENS AT 23°, 50°, AND 70° C[a]

(a) Data for tensile strength and stress at onset of crazing.

Material	NBS sample	Temperature (°C)	Tensile strength, σ_{max} (psi) (b)		Stress at onset of crazing, σ_c (psi)		σ_c/σ_{max} (percent)
			Average	Range	Average	Range	
Lucite HC201	L1d	23	8.06×10^3	$7.86 - 8.21 \times 10^3$	7.4×10^3	$7.2 - 7.5 \times 10^3$	91
		50	4.53	4.36 - 4.82	4.1	3.9 - 4.3	90
		70	2.28	2.03 - 2.43	[c]2.2	[c]2.0 - 2.4	96
Lucite HC202	L2d	23	10.00	9.76 - 10.3	9.7	9.4 - 10.2	97
		50	6.60	6.37 - 6.83	5.6	5.1 - 6.1	85
		70	4.43	3.99 - 4.92	3.8	3.2 - 4.2	86
Plexiglas I-A	P1a	23	8.22	8.07 - 8.35	8.0	7.9 - 8.2	98
		50	4.77	4.64 - 5.13	4.5	4.2 - 4.6	94
		70	2.31	1.97 - 2.54	[c]2.3	[c]1.9 - 2.5	99
Plexiglas II	P2a	23	10.35	9.85 - 10.8	9.7	9.2 - 10.2	94
		50	6.96	6.42 - 7.82	5.7	5.4 - 5.9	82
		70	5.10	4.42 - 5.83	3.9	3.5 - 4.6	75

[a]Tests were made on standard tensile specimens, Federal Specification L-P-406a, Method No. 1011, Type I. Testing speed was 0.05 in./min up to 10-percent elongation of specimen; strain gage was removed at this point and testing speed was increased to about 0.6 in./min. Six specimens, one from each half of each sheet of a sample, were tested for each average.

[b]Tensile strength is based on maximum load attained at testing speed of 0.05 in./min.

[c]For five specimens. On one specimen of group of six, onset of crazing occurred beyond the yield point and this value was not included.

TABLE II.- Concluded

TENSILE TESTS OF POLYMETHYL-METHACRYLATE SPECIMENS AT 23°, 50°, AND 70° C[a] - Concluded

(b) Data for permanent set, strain at onset of crazing, and modulus of elasticity.

Material	NBS sample	Temperature (°C)	Permanent set (percent) (d)		Strain at onset of crazing (percent)		Modulus of elasticity data[e]		
							Stress range (psi)	Secant modulus (psi)	
			Average	Range	Average	Range		Average	Range
Lucite HC201	L1d	23	1.5	1 - 3	2.7	2.5 - 2.9	$0 - 4.0 \times 10^3$	385×10^3	$372 - 457 \times 10^3$
		50	50	28 - 83	2.0	1.8 - 2.4	0 - 2.5	265	263 - 303
		70	[f]>110	(f)	3.1	2.0 - 5.6	0 - 1.2	150	141 - 253
Lucite HC202	L2d	23	4	0.5 - 11	4.2	3.6 - 5.2	0 - 5.0	405	392 - 435
		50	16	3 - 39	2.2	1.8 - 2.8	0 - 4.0	300	271 - 340
		70	42	9 - 60	2.2	1.9 - 2.6	0 - 2.5	230	217 - 256
Plexiglas I-A	P1a	23	14	2 - 36	3.4	3.3 - 3.7	0 - 4.0	375	364 - 400
		50	58	22 - 126	2.3	2.0 - 2.8	0 - 2.5	275	270 - 312
		70	[f]>110	(f)	2.9	2.1 - 4.5	0 - 1.2	160	166 - 200
Plexiglas II	P2a	23	3	1 - 6	3.8	3.3 - 4.2	0 - 5.0	390	385 - 408
		50	5	2 - 8	2.2	1.9 - 2.4	0 - 4.0	310	296 - 348
		70	21	2 - 70	1.7	1.6 - 2.1	0 - 2.5	275	263 - 323

[a]Tests were made on standard tensile specimens, Federal Specification L-P-406a, Method No. 1011, Type I. Testing speed was 0.05 in./min up to 10-percent elongation of specimen; strain gage was removed at this point and testing speed was increased to about 0.6 in./min. Six specimens, one from each half of each sheet of a sample, were tested for each average.

[d]Measured within a few minutes after specimen broke.

[e]For stress range indicated in each case.

[f]Specimen did not break. Experimental setup did not permit greater separation of grips than an amount corresponding to a permanent set of about 2.2 in.

TABLE III

STRESS AND STRAIN AT THRESHOLD OF CRAZING FOR POLYMETHYL-METHACRYLATE SAMPLES FROM TENSILE TESTS AT 23° C[a]

NBS sample	Preloading stress (psi) (b)	Tensile strength, σ_{max} (psi)		Stress on onset of crazing, σ_c (psi)		σ_c/σ_{max} (percent)	Strain at failure[c] (percent)		Strain at onset of crazing[c] (percent)	
		Average	Range	Average	Range		Average	Range	Average	Range
L1d	2.0×10^3	8.00×10^3	$7.65 - 8.31 \times 10^3$	6.6×10^3	$6.4 - 7.0 \times 10^3$	83	4.8	3.4 - 7.4	2.0	1.8 - 2.3
L2d	3.0	9.73	9.22 - 10.1	8.3	7.4 - 8.9	85	8.8	3.4 - 16.6	2.5	2.0 - 3.0
P1a	2.4	8.13	7.94 - 8.38	7.4	7.1 - 7.9	91	[d] [e]24	[d] [e]13 - 40	[d]2.6	[d]2.3 - 3.1
P2a	3.0	10.02	9.0 - 10.5	8.8	7.7 - 8.8	85	[d]7.0	[d]3.1 - 9.8	2.6	2.1 - 3.2
L1d	3.0	7.93	7.62 - 8.13	[d]6.7	[d]6.2 - 7.0	84	6.3	4.5 - 9.0	[d]2.1	[d]1.8 - 2.5
L2d	4.0	9.69	9.44 - 9.99	8.0	7.1 - 8.5	82	6.9	4.1 - 10.2	2.4	1.9 - 2.7
P1a	3.2	8.10	7.90 - 8.25	7.3	6.8 - 7.9	90	>18.8	8.6 - >5.5	2.6	2.2 - 3.2
P2a	4.0	10.29	9.86 - 10.5	8.8	8.2 - 9.4	86	8.4	7.6 - 9.5	2.8	2.3 - 3.2

[a]Tests were made on standard tensile specimens, Federal Specification L-P-406a, Method No. 1011, Type I. Testing speed was 0.05 in./min. Specimens were conditioned at 23° C and 50-percent relative humidity at least 3 weeks prior to test. Six specimens, one from each half of each sheet of a sample, were tested for each average. (Data from reference 8.)

[b]Specimens were subjected to this stress for 5 minutes to correspond to stress used for stress-solvent crazing of other sets of specimens for another investigation (reference 8). There is no significant difference between the two sets for any sample.

[c]Load-elongation graphs were obtained with a Southwark-Peters plastics extensometer and associated recorder. Crazing was observed visually as described in text.

[d]For five specimens.

[e]Two values estimated from permanent set. Gage was removed from these two specimens at 10-percent elongation and cross-head speed was increased to approximately 0.6 in./min.

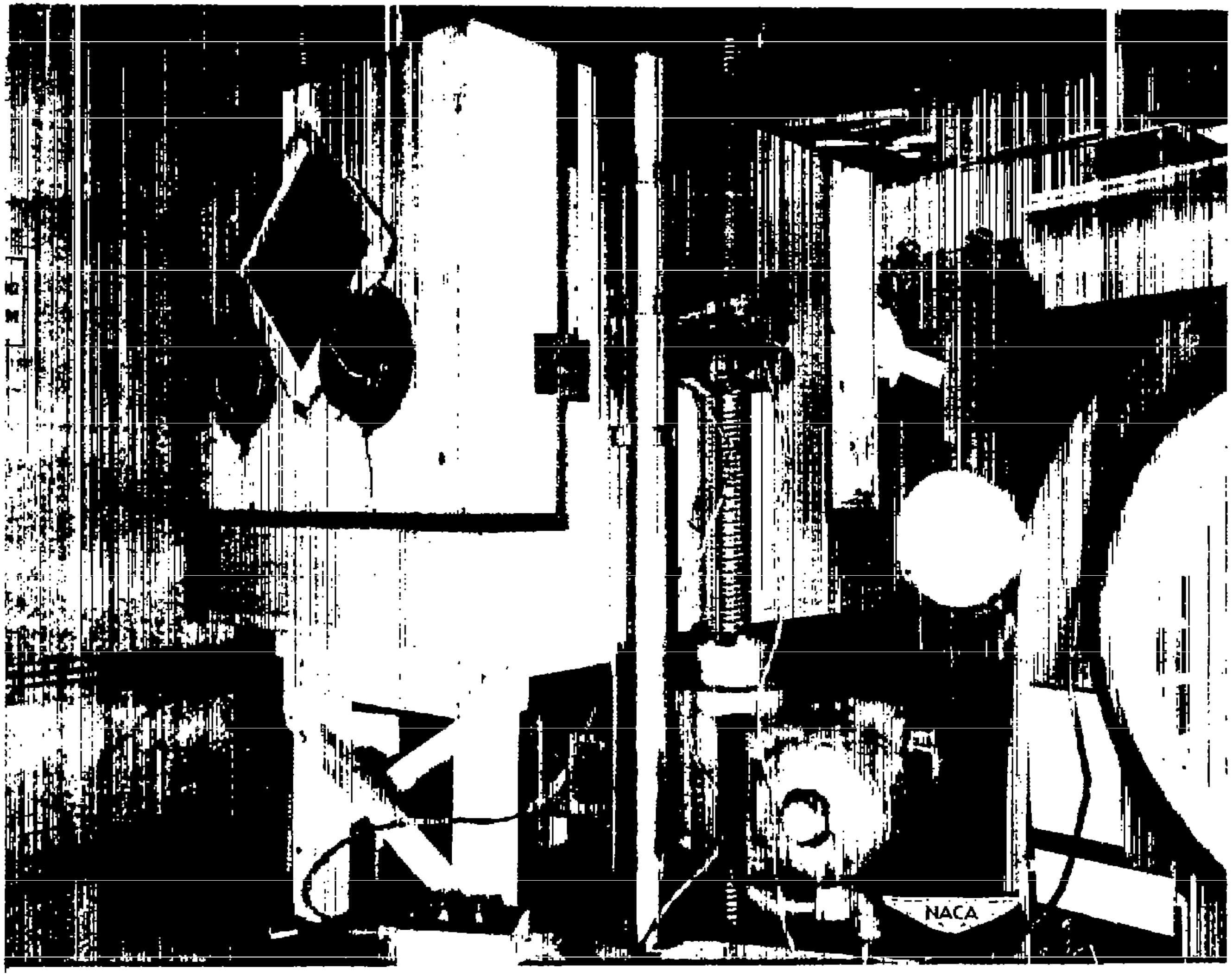

Figure 1.- Front view of tensile test enclosure in place in testing machine; conditioning unit can be seen at right.

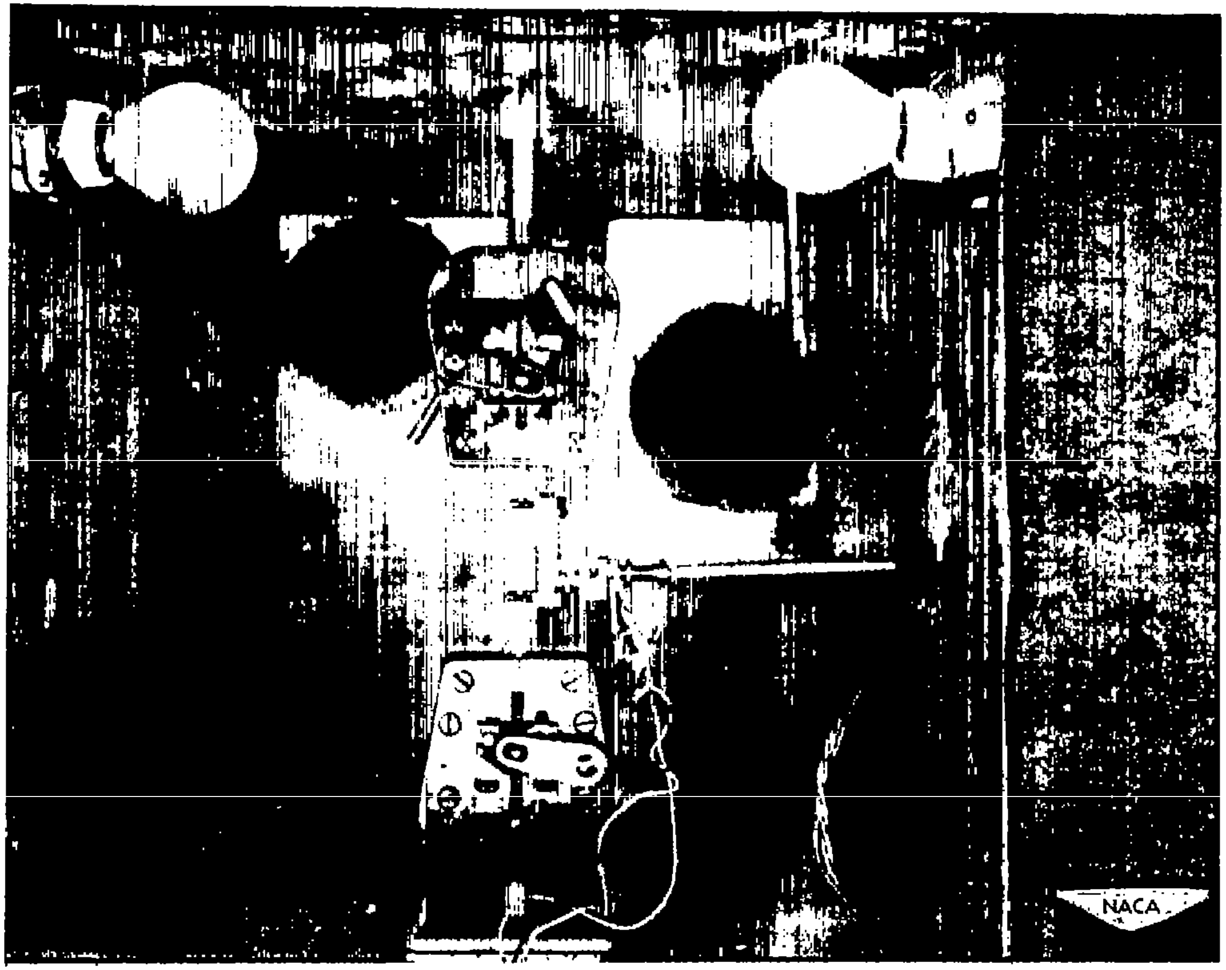

Figure 2.- Interior view of tensile test enclosure with specimen in grips and extensometer attached. Lamp used for observing crazing is not shown; this lamp was placed in rear left corner of box. Two lights shown in upper corners were out while crazing was being observed.

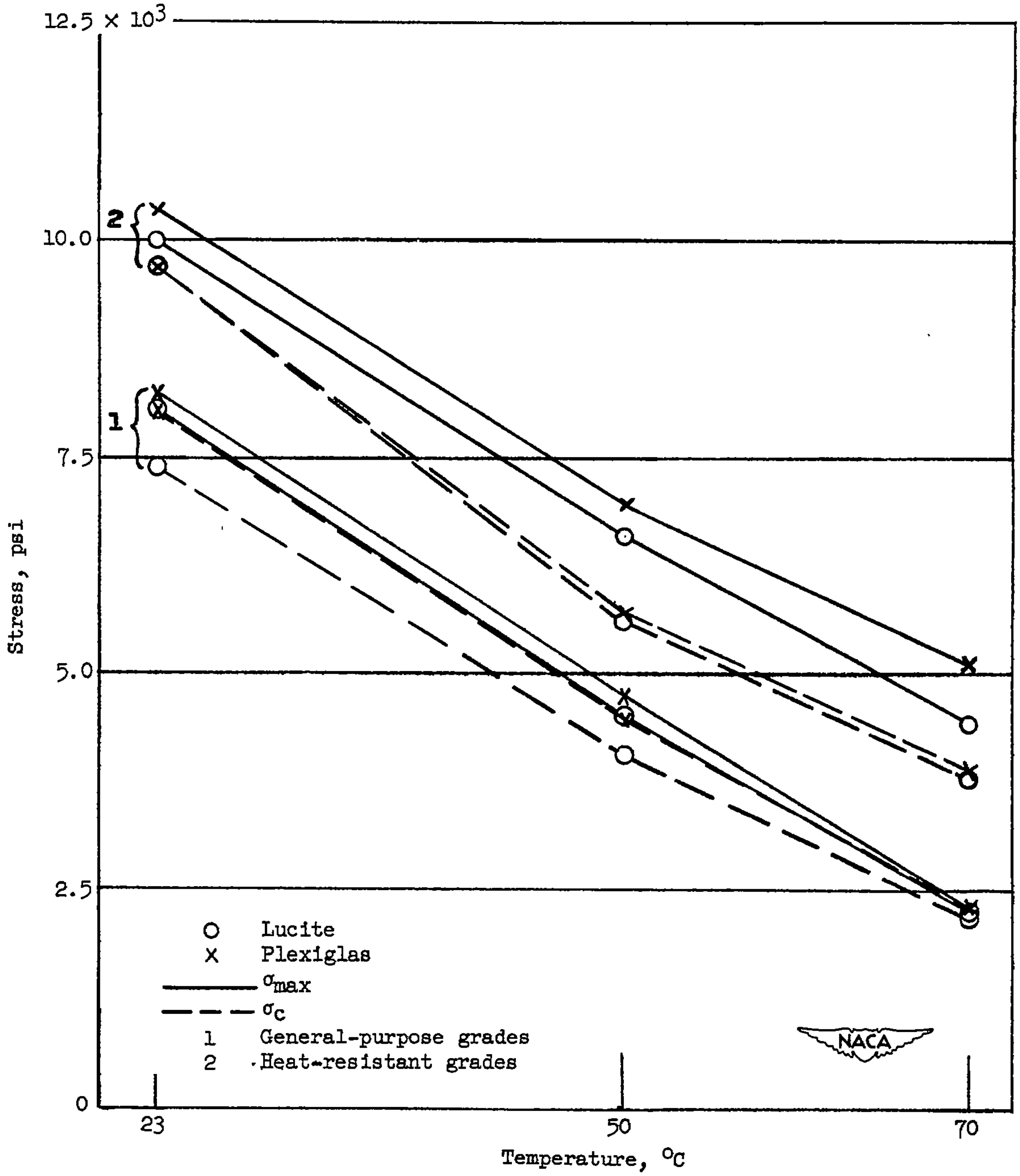

Figure 3.- Variation of tensile strength σ_{max} and stress at onset of crazing σ_c with temperature for acrylic plastics.

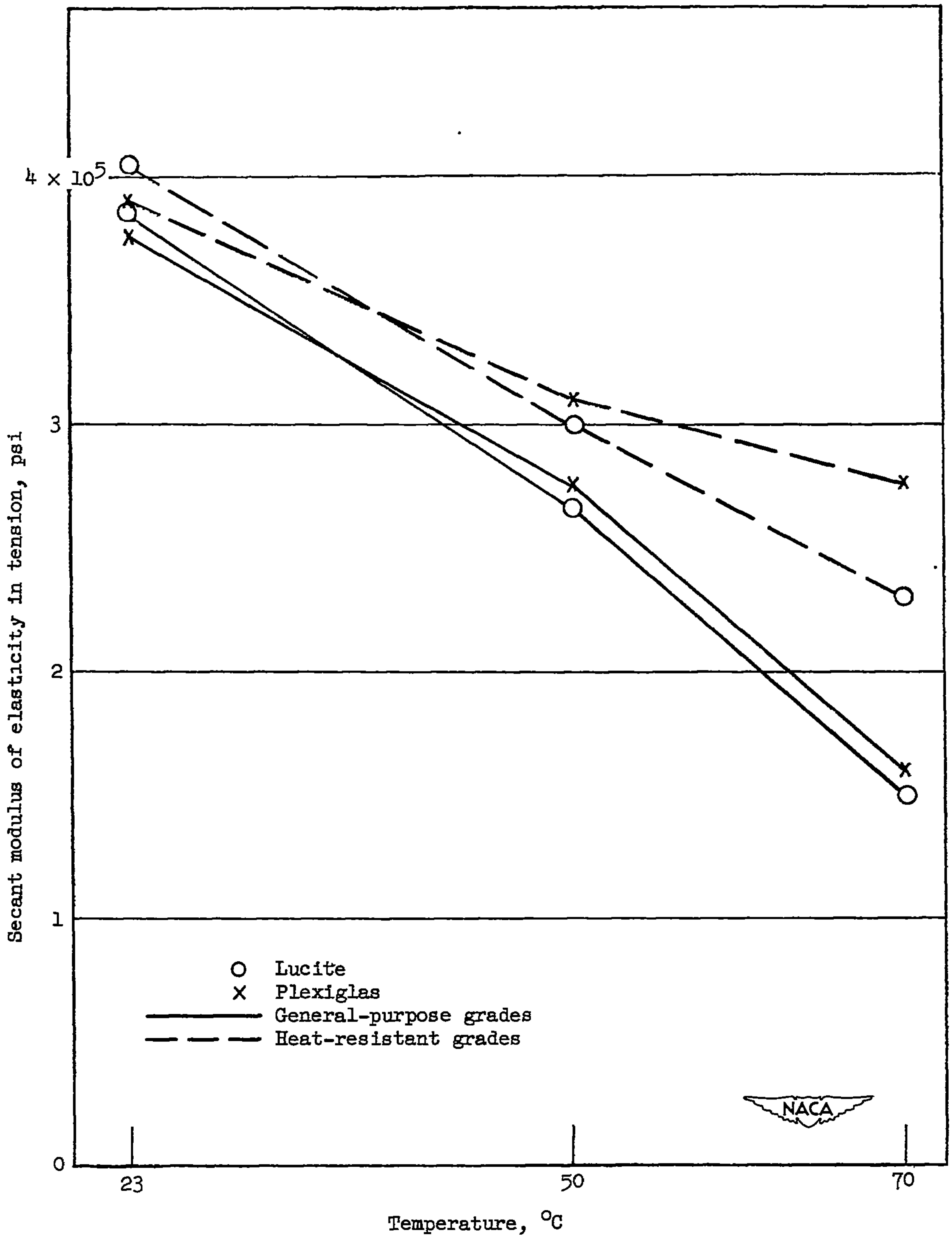

Figure 4.- Variation of tensile secant modulus of elasticity with temperature for acrylic plastics. Stress range is zero to about one-half of tensile strength.

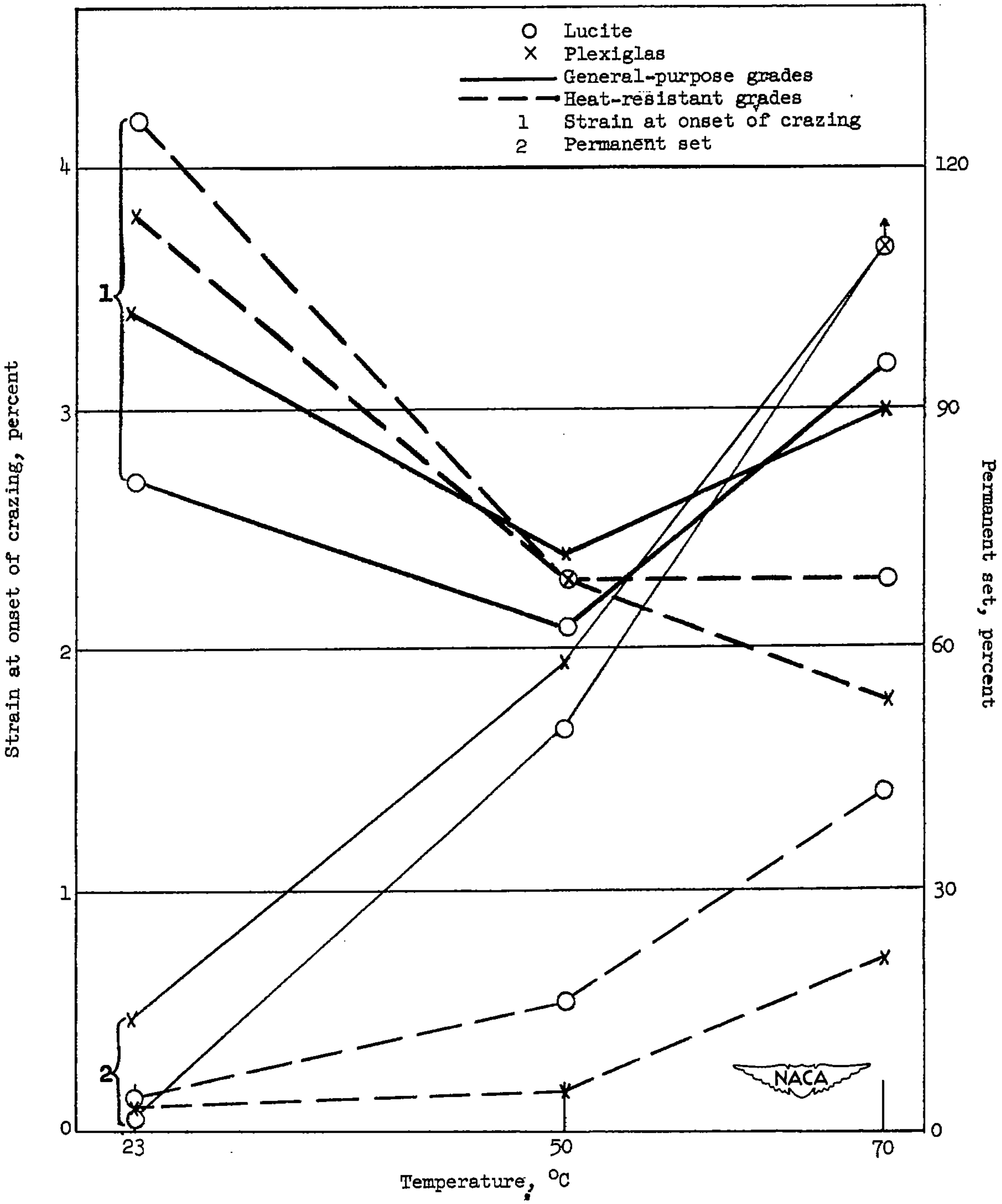

Figure 5.- Variation of strain at onset of crazing and permanent set with temperature for acrylic plastics.

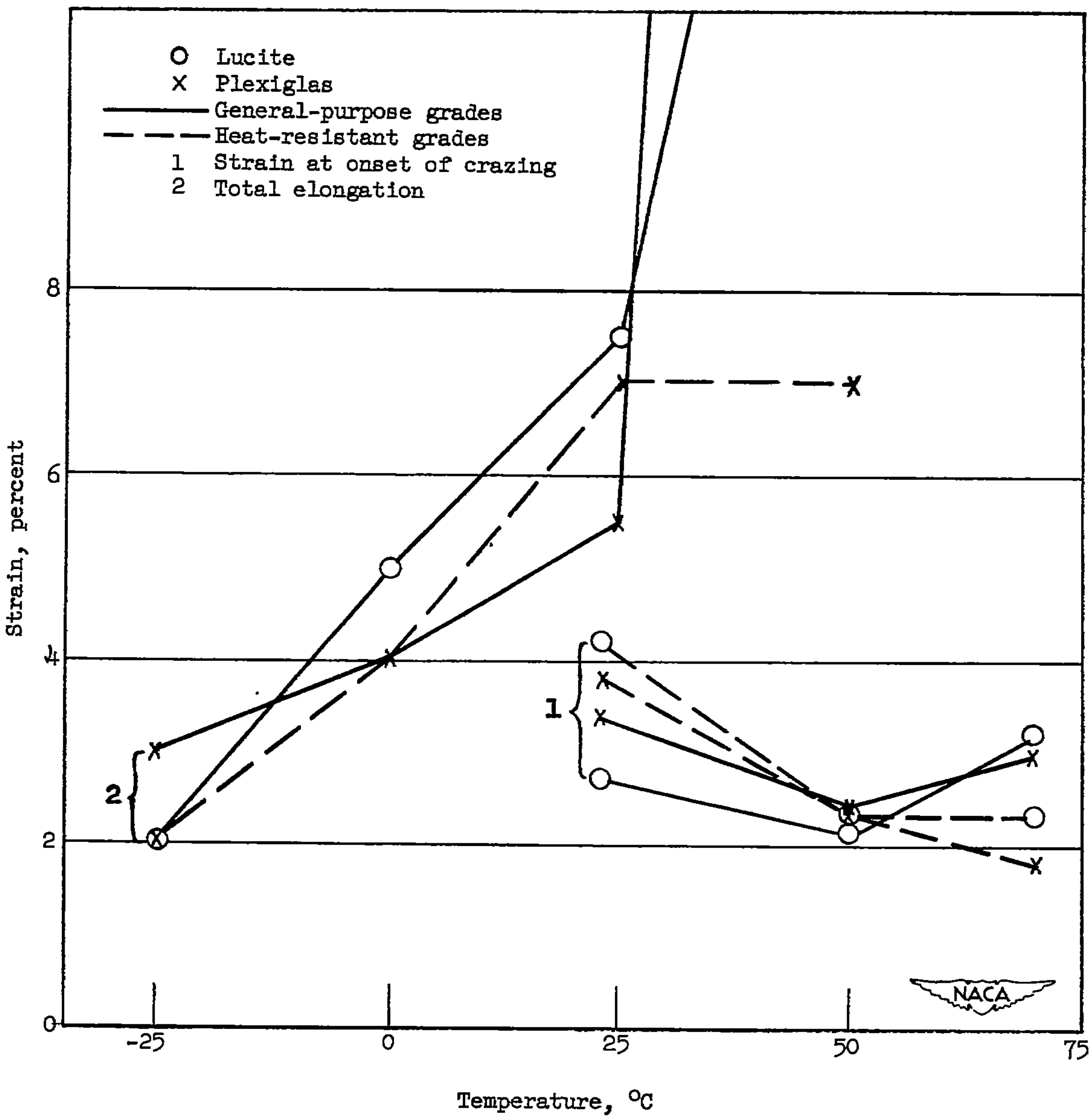

Figure 6.- Variation of strain at onset of crazing (data from fig. 5) and total elongation (data from NBS unpublished report to the Office of the Quartermaster General) with temperature for acrylic plastics.

NACA-Langley - 9-2-52 - 1000